ANGULAR-RATE ESTIMATION USING QUATERNION MEASUREMENTS

Ruth Azor* ,Itzhack Y. Bar-Itzhack[+] Julie K. Deutschmann[#],
and Richard R. Harman[#]

Abstract

In most spacecraft (SC) there is a need to know the SC angular rate. Precise angular rate is required for attitude determination, and a coarse rate is needed for attitude control damping. Classically, angular rate information is obtained from gyro measurements. These days, there is a tendency to build smaller, lighter and cheaper SC, therefore the inclination now is to do away with gyros and use other means and methods to determine the angular rate. The latter is also needed even in gyro equipped satellites when performing high rate maneuvers whose angular-rate is out of range of the on board gyros or in case of gyro failure.

There are several ways to obtain the angular rate in a gyro-less SC. When the attitude is known, one can differentiate the attitude in whatever parameters it is given and use the kinematics equation that connects the derivative of the attitude with the satellite angular-rate and compute the latter[1]. Since SC usually utilize vector measurements for attitude determination, the differentiation of the attitude introduces a considerable noise component in the computed angular-rate vector. To overcome this noise, the computed rate components can be filtered by a low pass filter of

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* Senior Control Engineer, Systems and Space Technology, Electronics Division, MBT, Systems Engineering Department. Israel Aircraft Industries, Inc. Yehud Industrial Zone 56000, Israel.

+ Sophie and William Shamban Professor of Aerospace Engineering. Faculty of Aerospace Engineering, Technion-Israel Institute of Technology. Member Technion Asher Space Research Institute. Haifa 32000, Israel. Tel: +972-4-829-3196. Fax: +972-4-823-1848. E-mail address: ibaritz@tx.technion.ac.il

Aerospace Engineer, Flight Dynamics Analysis Branch. Code 572, NASA Goddard Space Flight Center, Greenbelt, MD 20771.

the form $G(s) = (1/\tau)/(s+1/\tau)$. This, however, introduces a delay in the computed rate[1]. When using an active filter like a Kalman filter, the delay can be eliminated[2,3].

Another approach may also be adopted to the problem of angular-rate computation where the vector measurements themselves are differentiated. This approach was used by Natanson[4] for estimating attitude from magnetometer measurements and by Challa, Natanson, Deutschmann and Galal[5] to obtain attitude as well as rate. Similarly, Challa, Kotaru and Natanson[6] used derivatives of the earth magnetic field vector to obtain attitude and rate.

All these methods use differentiation of either the attitude parameters or of the measured directions which normally determine the attitude parameters. Another approach is that of using the attitude parameters, or the measured directions, as measurements in some kind of a Kalman filter. In this case the kinematics equation that connects the attitude parameters or the directions with their derivatives are included in the dynamics equation used by the filter thereby, as will be shown in the ensuing, *the need for differentiation is eliminated*[7,8]. New sensor packages have been introduced lately that yield the SC attitude in terms of the attitude quaternion[9]. Therefore it is possible to use the quaternion supplied by such sensors as measurements and, as mentioned before, eliminate the need for differentiation.

In this paper we present an algorithm for estimating the angular-rate vector of a gyro-less satellite using quaternion measurements. In order to examine the new algorithm, two approaches are compared. In the first approach, raw quaternion measurements are fed into two different filters; namely, a Pseudo-Linear Kalman Filter (PSELIKA) and a State Dependent Algebraic Riccati Equation (SDARE) filter. For the sake of comparison, another approach is tested, in which the measurements *are* differentiated to yield a coarse rate measurement that is then fed into the same two filters. Both filters rely on the ability to decompose the non-linear angular-rate dependent part

of the dynamics equation of a rigid body into a product of an angular-rate dependent matrix and the angular-rate vector itself. This decomposition, which is not unique, enables the treatment of the nonlinear spacecraft dynamics model as a linear one and, consequently, the application of the PSELIKA filter as well as the SDARE filter which is a special, more effective, Kalman filter that is based on solving the State Dependent Algebraic Riccati Equation in order to compute the Kalman gain matrix. This eliminates the need to propagate and update the filter covariance matrix.

Actual Rossi X-Ray Timing Explorer (RXTE) satellite flight data is used to test these algorithms, and results of these tests are presented in the full paper which demonstrate the efficiency of the suggested estimators.

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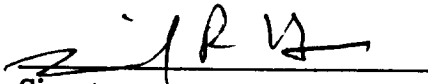
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